EFFECT OF NITROGEN ON THE ELASTOMECHANICAL PROPERTIES OF AUSTENITIC CHROMIUM-NICKEL STEELS

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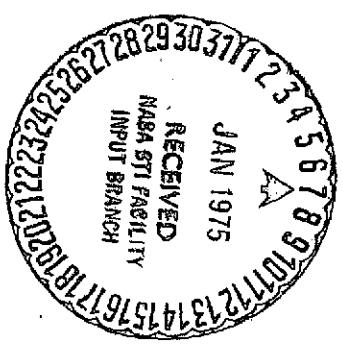

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16. Abstract In an austenitic steel (20% Ni, 20% Cr), addition of 0.29% nitrogen increases the moduli of elasticity and shear. Damping behavior of the steel containing nitrogen differs in the solution-annealed and age-hardened states. Damping is increased by interstitial nitrogen. Precipitation during brief age hardening at 800°C causes an anomaly in damping at 300°C and a shift in the damping curve above 500°C. Stress-induced diffusion of nitrogen atoms between interstitial sites and the nitride phase precipitates immediately nearby and/or a suppression of grain boundary relaxation due to the coverage of grain boundaries by nitride precipitates is suggested as the cause.

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EFFECT OF NITROGEN ON THE ELASTOMECHANICAL PROPERTIES OF AUSTENITIC CHROMIUM-NICKEL STEELS

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The increasing importance of nitrogen as an alloying element /85* in austenitic chromium-nickel steels has caused increased attention to be devoted in the past to its solution and precipitation behavior in the corresponding alloy systems. A report was recently given by K. Bungardt, H. Laddach and G. Lennartz [1] on what was known so far and on their own more advanced studies. As a supplement to the results reported there, which were obtained by metallographic methods, by the isolation of residues, X-ray-physics studies and the testing of a number of mechanical properties, a number of findings from elastomechanical studies will be presented below. Emphasis was placed here on the two steels labeled Nos. 2 and 10 in the above article [1], both containing about 20% Ni and 20% Cr, the former being smelted with very little nitrogen, the other with 0.29% N, as can be seen from Table 1. Their elastomechanical properties were determined both in the kHz range using bar-shaped specimens with the aid of an Elastomat [2], and in the measurement range around 1 Hz, using wire-shaped specimens with the aid of a torsion pendulum [3]. In order to determine the effect of an advanced precipitation of nitrides, specimens of both material were first tested in the solution-annealed state (1150°C, 30 min, oil) and then after age hardening at 800°C for times ranging from 6 min to 1200 min.

The results obtained in the kHz range, shown in Figs. 1a and 1b, show that no appreciable change in the elastic properties characterized by the modulus of elasticity and the modulus of

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* Numbers in the margin indicate pagination in the foreign text.

TABLE 1. CHEMICAL COMPOSITION OF THE MATERIALS STUDIED

Steel No.	Content in % weight					
	C	Si	Mn	Cr	Ni	N
2	0,014	0.44	1,54	20,94	19.94	0,018
10	0,026	0,39	1,70	21,02	20.00	0.29

shear is connected with the precipitation of chromium nitrides. In spite of the dispersion which occurs, which only amounts to about ±1%, the addition of nitrogen to steel No. 10 causes a slight increase in the moduli which is even retained after age hardening for up to 1200 min.

The damping properties of the two steels, with values of about $Q^{-1} = 1 \cdot 10^{-3}$ at room temperature, determined with the aid of the torsion pendulum, likewise indicate no distinct effect due to difference in nitrogen content. Aging at 800°C, which reduces the /86
notched-bar impact toughness of steel No. 10 from about 240 I to about 70 I (DVM [German Society for the Testing of Materials] specimen) in about 20 hours [1], produces just as little effect on damping properties. Only a study of the two materials at temperatures above room temperature, up to about 800°C, indicates greater differences in elastomechanical behavior. To illustrate this observation, both damping and the ratio G_T/G_{RT} of the moduli of shear are compared in Figs. 2a-2e for selected age-hardening times for the two steels. All of the damping curves initially exhibit a basically similar shape, characterized by a slight rise to about $Q^{-1} \approx 0.0015$ up to a temperature of about 500°C, followed by a steep rise. While damping is practically independent of temperature for all tested age-hardened states in the indicated lower temperature range for low-nitrogen steel No. 2, however, anomalies are observed in the case of steel No. 10, containing nitrogen. Starting from a pronounced rise in damping

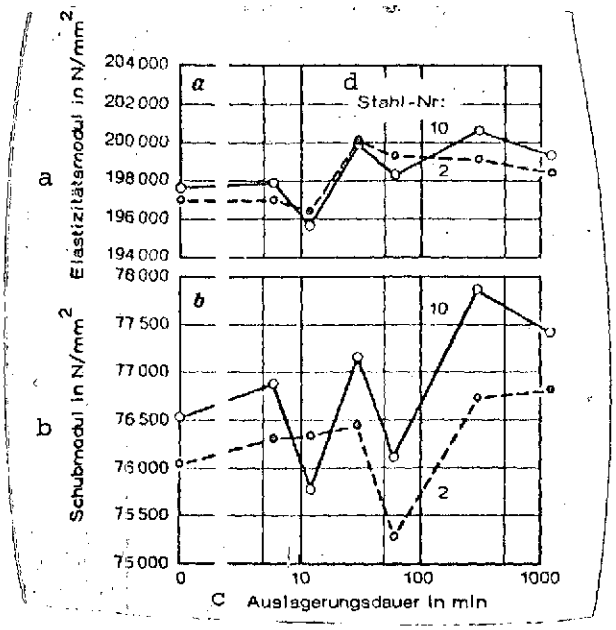

Fig. 1. Effect of increasing age-hardening time at 800°C on the moduli of elasticity and shear, at room temperature, of a low-nitrogen and a high-nitrogen chromium-nickel steel containing 20% Cr and 20% Ni.

Key: a. Modulus of elasticity
b. Modulus of shear
c. Age hardening time
d. Steel No.

in the range from about 200 to 500°C in the solution-annealed state, several flat damping peaks develop in each case for aging times between 6 and 60 min, as can be seen in Figs. 2b and 2c. For longer aging times, these damping phenomena initially recede again (cf. Fig. 2d, 5 hours of age hardening), only to appear again in altered form, as a shallow saddle, after 20 hours of age hardening.

In the range of the steep rise in damping at temperatures above 500°C, the action of added nitrogen becomes most distinctly visible. All specimens in the age-hardened state containing nitrogen exhibit a distinct shift in their observed steep rise, in the direction of higher temperatures, relative to the low-nitrogen steels age-hardened for the same time. In just the solution-annealed state, in which the steel containing nitrogen exhibits the highest damping values, the material behaves completely differently. The ratios presented can be shown graphically if the damping value measured at 600°C is considered /87 representative and is plotted for both materials as a function of age-hardening time at 800°C, as has been done in Fig. 3. In the case of low-nitrogen steel No. 2, an increase in damping with increasing age-hardening time is found to begin with the solution-annealed state. The damping value measured for high-nitrogen

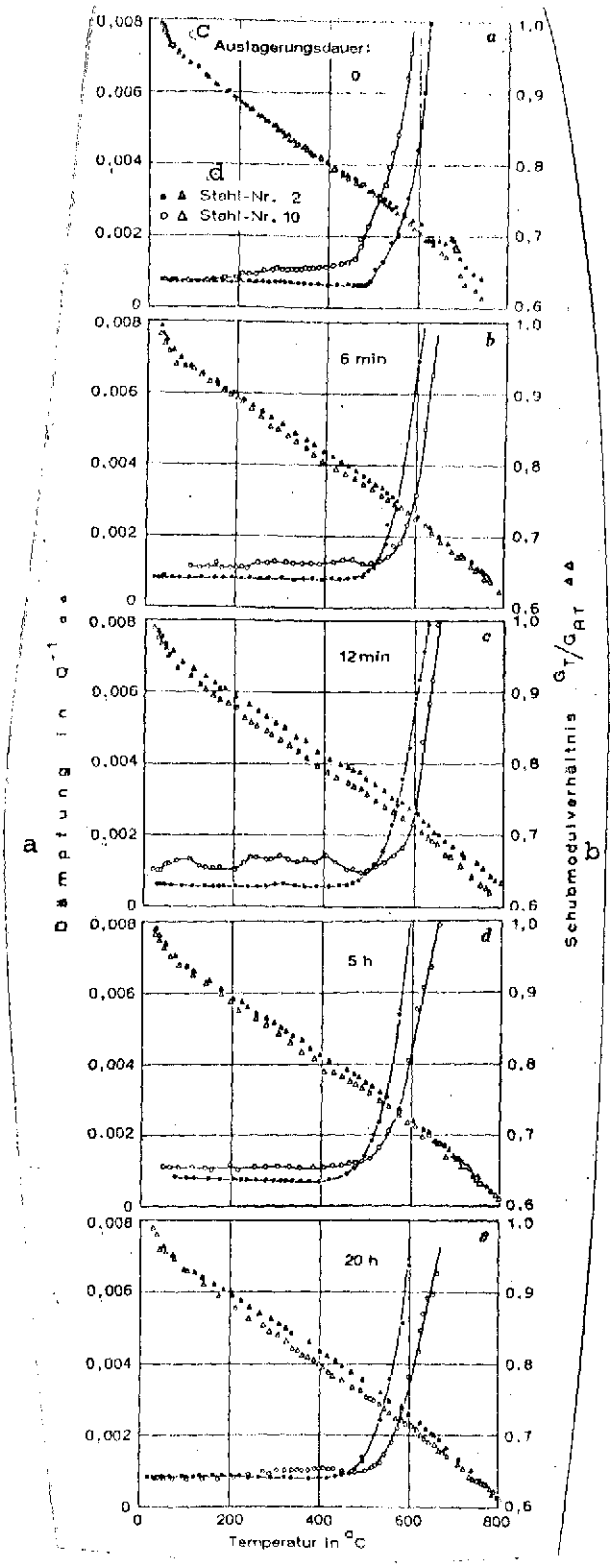

Fig. 2. Damping (●○) and ratio of moduli of shear [continued on following page].

steel No. 10 in the solution-annealed state is about twice as high as that for the low-nitrogen steel, but age-hardening for 6 min at 800°C is enough to lower it from $Q^{-1} = 0.009$ to 0.003, and as aging time increases, it still amounts to only about half of the value for the low-nitrogen steel in each case. As supplementary information, the ratio G_T/G_{RT} of moduli of shear are also plotted in Figs. 2a-2e, from which the drop in the modulus of shear with increasing temperature can be seen in general, with a practically linear curve in the range between 100°C and 600°C, with a temperature coefficient of about 27.5 $N/mm^2°$. It is notable here that the relative drop in the modulus of shear for the solution-annealed states of both materials is practically the same, whereas after age-hardening, a more pronounced drop in the ratio of moduli of elasticity also occurs here, always in the temperature range of the occurrence of damping anomalies in the high-nitrogen steel.

Caption to Fig. 2, continued

(ΔΔ) as functions of temperature for a low-nitrogen and a high-nitrogen chromium-nickel steel containing 20% Cr and 20% Ni after different age-hardening times at 800°C.

Key: a. Damping
b. Ratio of moduli of shear
c. Age-hardening time
d. Steel No.

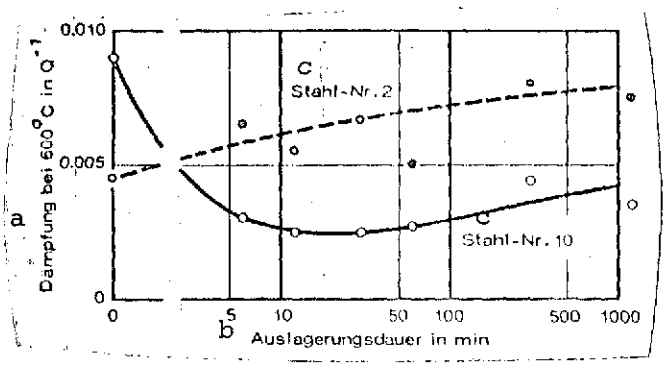

Fig. 3. Effect of increasing age-hardening time at 800°C on the damping at 600°C of a low-nitrogen and a high-nitrogen chromium-nickel steel containing 20% Cr and 20% Ni.

Key: a. Damping at
b. Age-hardening time
c. Steel No.

While the described damping curve for the low-nitrogen steel No. 2 indicates no peculiarities and was to be expected to have the observed shape, the behavior of high-nitrogen steel No. 10 is surprising. It is known from earlier articles [4-6] that, much as in the body-centered cubic lattice, damping phenomena due to atoms like carbon or nitrogen dissolved interstitially are also possible in the face-centered cubic lattice.

While every foreign atom dissolved interstitially in the body-centered cubic lattice causes an elastic stress with non-cubic symmetry and thus can be excited to stress-induced diffusion (Snoek effect), however, this is not possible in the crystal of a face-centered cubic element under the stress which develops, likewise with cubic symmetry.

Damping effects only occur when the levels of the element dissolved interstitially becomes so high that pairing occurs [7]. But even in the substitution-type mixed crystal, such as in the case at hand, the different sizes and structures of the various metal atoms produce a number of octahedral interstitial sites which do not possess the simple cubic symmetry and, consequently, when occupied by atoms dissolved interstitially cause a local stress which in turn leads to stress-induced diffusion. Thus V.D. Verner [6] observed a damping maximum at 330°C (measurement frequency 2 Hz) in steel containing 19% Mn and 7% Cr, the peak value of which is a linear function of nitrogen content in the range studied, from 0.22 to 0.77%. Although temperature and peak height for the damping anomalies determined in our own studies correspond to this, the fact that the phenomenon occurs only after age hardening indicates a peculiarity. It would be conceivable that a migration mechanism for nitrogen atoms dissolved interstitially in the austenite lattice and precipitated in the nitride phase is involved here, a process analogous to that which was suspected in damping phenomena in titanium-hydrogen alloys [8]. Apparently, favorable conditions for occurrence of the damping maximum, whose appearance and size are affected appreciably during the course of prolonged age hardening, are provided right at the beginning of precipitation, i.e. after aging for just 6 min at 800°C. A connection between the breakdown in this effect after 5 hours of age hardening and the loss of coherence in the precipitates must remain just a suspicion for the time being.

Nitride precipitates covering the grain boundaries must be considered responsible for the reduction in damping within the region of the high-temperature rise (cf. Fig. 3), which was likewise observed even after the shortest age-hardening time for high-nitrogen steel No. 10. In this temperature range, the damping phenomenon can be attributed largely to the behavior of the grain boundaries.

Concepts like those developed for the suppression of the grain boundary maximum upon precipitation of the σ-phase in ferritic chromium steels [9] should also be applicable here.

Summary /88

It was shown with the aid of elastomechanical studies performed on an austenitic steel containing about 20% Ni and 20% Cr that the addition of 0.29% nitrogen increases both the modulus of elasticity and the modulus of shear, regardless of whether the nitrogen is dissolved interstitially or precipitated in the steel as nitride. Differences are observed in the damping behavior of the steel containing nitrogen in the solution-annealed and the age-hardened state. A rise in damping is caused by the nitrogen dissolved interstitially throughout the temperature range studied, from room temperature to about 800°C. The precipitates formed after just 6 min during age hardening at 800°C cause a damping anomaly in the temperature range around 300°C and shift the steep rise in damping above 500°C to elevated temperatures. A stress-induced diffusion of nitrogen atoms between interstitial sites and the nitride phase precipitated immediately nearby and/ /or a suppression of grain boundary relaxation due to the coverage of grain boundaries by nitride precipitates is suggested as the cause.

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